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Simulation of merging pedestrian streams at T-junctions

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Abstract

We investigate the applicability of the Floor Field Cellular Automaton Model to merging pedestrian streams at T-junctions. For this purpose we examine the possibility to calibrate the model by comparing density profiles and fundamental diagrams with results of experiments. Due to the discreteness of the cellular automaton model the resolution of the predicted densities is very limited. For this reason we examine different methods of density determination in cellular automata models. We consider two methods on a refined grid, the Voronoi approach and a Gaussian approach. Based on the obtained data, the comparison with the experiments is carried out.

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1. Introduction

The design of increasingly larger public buildings and safety issues at major events have lead to an increasing need for computer simulations of pedestrian streams. In the past, several models were developed in order to facilitate this, see e.g. the reviews by Schadschneider et al. (2009) and Schadschneider et al. (2010). At the present time there is still a lack in the verification of the models against experiments, especially in more complex scenarios of interacting pedestrian streams. We focus on the established Floor Field Model and test it on the basis of the simplest situation of two mixing pedestrian streams, the T-junction. We also compare different methods for the determination of the density in cellular automata models.

2. Floor Field Model

The Floor Field Model (FFM) has been introduced in (Burstedde et al. (2001); Kirchner et al. (2003)) as a cellular automaton (CA) model for pedestrian dynamics. The temporal development of each pedestrian is determined by simple stochastic rules which take into account the interactions with other pedestrians and the infrastructure. Pedestrians move on a space which is divided into cells of size (40 cm) × (40 cm). Each cell can only be occupied by one pedestrian. The stochastic rules are encoded in two fields, the static and the dynamic floor field S_{ij} and D_{ij}, respectively,

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which determine the transition probabilities p_{ij} to one of the nearest neighbour cells (i, j):

$$p_{ij} = N \cdot \exp(k_s \cdot S_{ij}) \cdot \exp(k_d \cdot D_{ij}) \cdot (1 - n_{ij}) \cdot \xi_{ij} \,. \tag{1}$$

Here n_{ij} is the occupation number of the target cell, ξ a wall factor which is 0 for inaccessible cells (e.g. walls) and 1 otherwise, and N a normalisation constant. k_s and k_d are coupling constants to the two floor fields. The static floor field S_{ij} is usually determined by the distance of the cell (i, j) to the exit. The dynamic floor field D_{ij} is created by moving pedestrian and has its own dynamics (diffusion and decay). It encodes the tendency of pedestrians to follow moving persons. In addition to the above parameters the transition probability depends on a friction parameter μ which decides whether it comes to a transition in the event of a conflict (Kirchner et al. (2003)).

For the T-junction scenario we have to specify the sites where pedestrians enter the junction. These entry cells are occupied with a certain probability α in each time step. At the exit cells pedestrians are removed from the system with probability β.

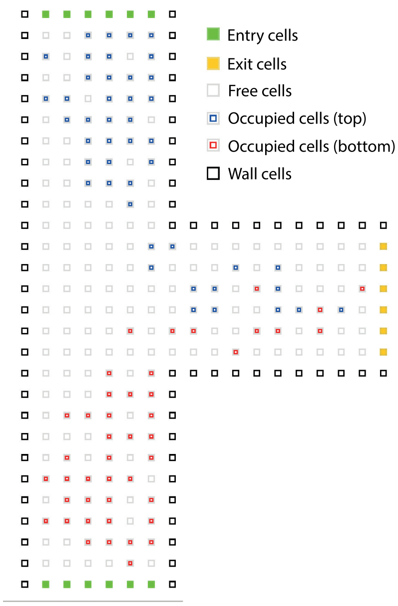

Fig. 1. Space discretisaton of the T-junction as used for the simulations with the FFM. The color code indicates the entry and exit cells and walls.

3. Density definitions in CA models

There are several density definitions that have been used for pedestrian systems, but all of them have certain limitations. For a more complete discussion, see Schadschneider et al. (2009) and Steffen and Seyfried (2010). Here we discuss and compare density definitions specifically in CA models where the discreteness of space leads to additional problems.

3.1. Standard method

The simplest method to determine the density $\rho(\vec{r})$ uses the number of persons $N(A)$ in a predefined area A, i.e.

$$\rho(\vec{r}, t) = \frac{N(A)}{A} \,. \tag{2}$$

This density is usually assigned to the position $\vec{r}$ in the center of the area. In CA models this definition is based on a neighbourhood of a cell. In the simplest case the area consist of just the center cell. Then, at any time, only two densities are possible (0 or 1). The standard choice is therefore based on the Moore neighbourhood of the center cell. For a square lattice it consists of 9 cells. The density is then quantized in multiples of 1/9, i.e. $\rho(\vec{r}) = n/9$ with $n = 0, 1, \dots, 9$. For cells near walls different quantized values arise. Therefore the main disadvantages of the standard method are the low resolution and the tendency to artefacts due to the edge effects.

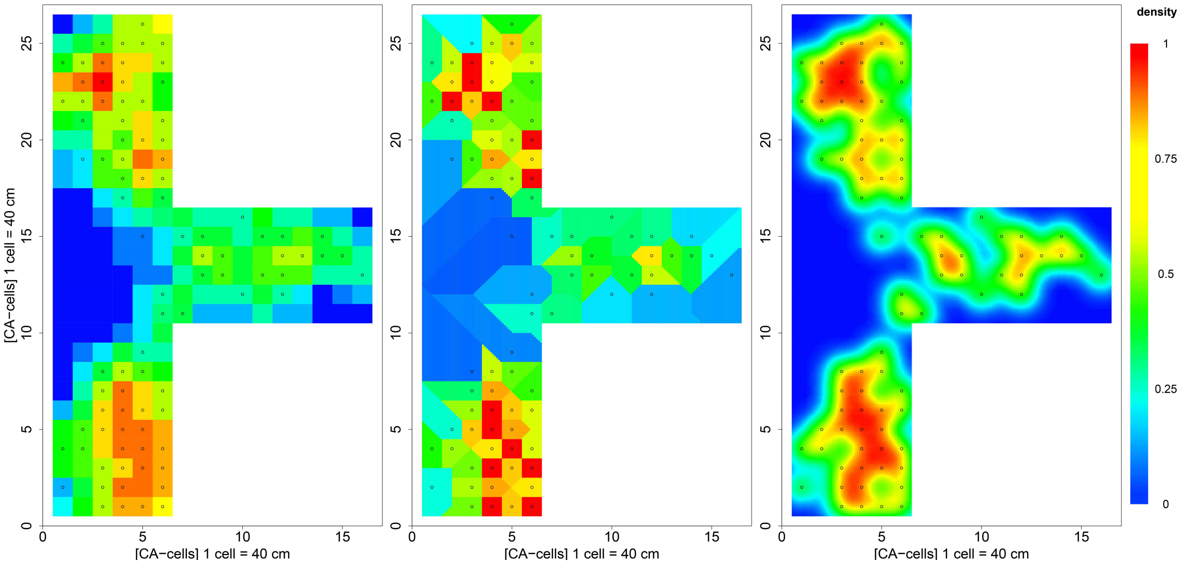

Fig. 2. Density for the configuration shown in Fig. 1 as determined by standard method (left), Voronoi method (center) and Gaussian method (right)

3.2. Voronoi method

The Voronoi method introduced by Steffen and Seyfried (2010) has several advantages over the standard method. Here we adopt it for CA models. First, Voronoi cells for all pedestrians are determined. Then the density is calculated from the surface area A_j of the Voronoi cell for each pedestrian j. The density of the area covered by Voronoi cell j is given by

$$\rho_j = \frac{1}{A_j} \,. \tag{3}$$

The Voronoi method can be implemented in different ways.

3.2.1. Exact method

First the Voronoi decomposition is determined by the algorithm of Fortune (1986). The algorithm receives the coordinates of the occupied positions as input. The output is a list of edges which are assigned to the occupied positions in CA. Because the algorithm does not consider margins, the obtained edges are generally not finite. Therefore infinite edges have to be pruned to borders. After this procedure it is possible to extract closed cells provided that the border is a convex polygon. In the case of a T-junction, the boundary is not convex which means that there is no general algorithmic solution to close the cells. A possible solution is the restriction to convex subregions. If the cells have been correctly determined, the areas of each cell (irregular polygons) can be calculated by triangulation. Because the exact determination does not work for all situations we tested another approach where the cells are determined approximately on a refined grid.

3.2.2. Approximate method (Flood fill algorithm)

In the first step, the resolution is refined by a factor of 10 by dividing each cell of the FFM into 10×10 subcells. In the flood fill algorithm, occupied cells propagate on the refined grid to their Moore neighbourhood. The propagation ends at walls or when propagation fronts from different occupied cells meet. The disadvantage of this method is the ambiguity at the cell boundaries. When two growing regions spread simultaneously to a cell, there will be a conflict which leads to ambiguities. The conflict can be resolved by choosing the dominant region in the Moore neighbourhood. As can be seen in Fig. 2, only angles of 0°, 45°, 90° between the regions are possible. This effect leads to deviations from the exact determination, particularly at low densities.

3.3. Gaussian method

The third approach is the CA-implementation of the Gaussian method of density determination. A general description of this method can be found in Helbing et al. (2007). In order to achieve an improved resolution the cells are divided into subcells again. In this case we choose 11×11 subcells. The density of each sub-cell $\vec{r}$ is defined as

$$\rho(\vec{r}, t) = \sum_j f(\vec{r}_j(t) - \vec{r}) \tag{4}$$

where $\vec{r}_j(t)$ is the position of the centered sub-cell of the cell that is occupied by the pedestrian j at time t. The contribution to the sum is zero if the position $\vec{r}_j(t)$ of the pedestrian j is not in the defined vicinity of $\vec{r}$. $f(...)$ is a Gaussian, distance-dependent weight function with cut-off. The cut-off follows from the defined vicinity. With a suitable choice of $f(...)$, the standard method can be viewed as a special case of the Gaussian method.

3.4. Comparison

In the comparison of the methods one should take into account the meaning of density in pedestrian dynamics. It provides information on the available space and thus the mobility of the individuals. In the standard method the density is a local measure for the mobility since it is determined only by the Moore neighborhood of a cell. Information about the mobility beyond this neighbourhood is not considered. In contrast, in the Voronoi method the area which determines the density is dynamic and depends on the distribution of occupied positions. In this sense, the Voronoi method takes into account global information. The extension of the Voronoi cells and their associated densities provide information about the number of time steps a pedestrian can move without conflict. This gives a very good representation of the mobility. Furthermore it is possible to achieve a more accurate classification by the refinement. For more details on the comparison of the Voronoi method with the standard method, see Craesmeyer and Schadschneider (2014).

Although the determination of the densities by the Gaussian or standard method has a similar approach, the introduction of a weight function in combination with the refinement, leads to a significant improved resolution and the absence of artifacts. This is recognizable especially in the time-averaged representation (see Sec. 4.2), as compared with the standard and Voronoi approach. Another advantage of the Gaussian method is its flexibility. The function $f(...)$ can be chosen arbitrarily in principle. The Gaussian function has been found to be very suitable also for the case of CA models.

4. Comparison with experiments

For the validation of the model we have focused on two important aspects, the fundamental diagram and the density profile. A good agreement with experiments is particular important for evacuation scenarios .

4.1. Fundamental diagram: flow vs. density

The simulated fundamental diagrams show a good agreement with those from the experiment. A lower scattering is noticeable in the simulation data. To record the measurement points in the steady state, the measurement is started after 500 time-steps in the CA. The flux-density value pairs result from measurements averaged over 500 steps. The density is controlled by varying the input rate.

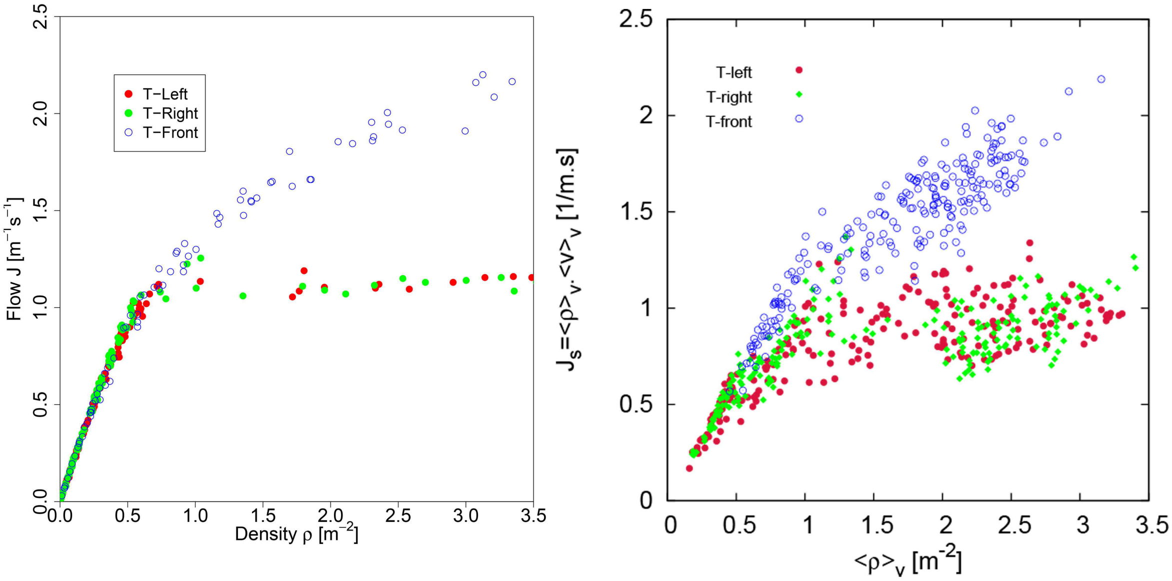

Fig. 3. Fundamental diagrams: Simulation with $k_s = 3$ and $k_d = 1$ (left) and experimental data (Zhang et al. (2011, 2013)) (right)

4.2. *Density profile*

The density profiles shown in Fig. 4 are based on a temporal averaging in the steady state. For determining the densities from the experimental data the Voronoi method was used. This process is described in more detail by Zhang et al. (2011, 2013).

For the determination of the density profile of the simulation, the methods described above were used. In the Voronoi method artifacts remain even after temporal averaging. This can be attributed to several factors, especially the discreteness of the space in the CA and the angle constraints caused by the floodfill approach.

The density profile based on the Gaussian method is free of such artifacts. This is already recognizable in the presentation in the previous chapter, which is based on a single temporal snapshot.

The two density profiles from the simulations show a good agreement with the experiment. Inhomogeneities at the entrance in the experiment that were arising from the structure are not found in the simulation. They could have been realized through a different distribution of input rates.

5. Results and Outlook

We have studied the behavior of merging pedestrian streams using a cellular automaton approach. Our results show that the Floor Field Model gives a good description of the dynamics at T-junctions. A good agreement with experimental results is found with a standard setting of the basic parameters. This applies both for the fundamental diagram as well as for the density profile.

Due to the discreteness of space, an accurate determination of densities in CA models is difficult. We have proposed two methods that lead to a significant improvement in resolution compared to the standard method. Quantization effects due to the discreteness of the CAs and other artefacts can avoided. This allows a much easier comparison of simulation results from CA models with experiments.

References

Burstedde, C., Klauck, K., Schadschneider, A., Zittartz, J., 2001. Simulation of pedestrian dynamics using a 2-dimensional cellular automaton. Physica A 295, 507.

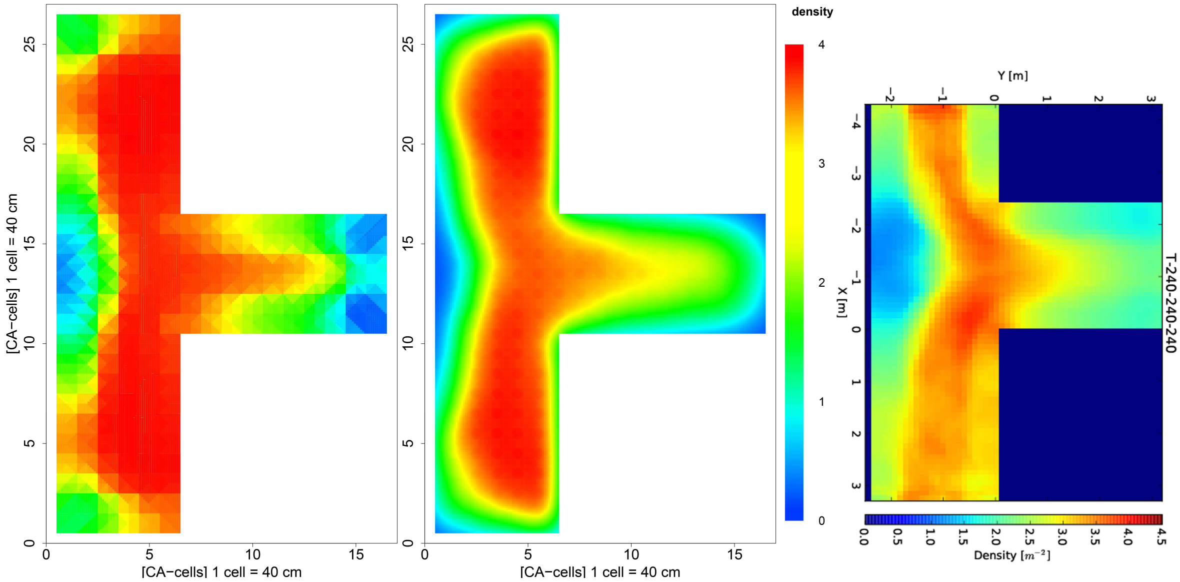

Fig. 4. Density profiles: Voronoi method: FFM (left), Gaussian method FFM: (center), Voronoi method: experiment (right)

Craesmeyer, M., Schadschneider, A., 2014. Simulation of merging pedestrian streams at T-junctions: comparison of density definitions, in: Chraibi, M., Boltes, M., Schadschneider, A., Seyfried, A. (Eds.), Traffic and Granular Flow '13. Springer. To appear.
Fortune, S., 1986. A sweepline algorithm for Voronoi diagrams. Proc. 2nd Ann. Symposium on Computational Geometry , 313.
Helbing, D., Johansson, A., Al-Abideen, H., 2007. The dynamics of crowd disasters: An empirical study. Phys. Rev. E 75, 046109.
Kirchner, A., Nishinari, K., Schadschneider, A., 2003. Friction effects and clogging in a cellular automaton model for pedestrian dynamics. Phys. Rev. E 67, 056122.
Schadschneider, A., Chowdhury, D., Nishinari, K., 2010. Stochastic Transport in Complex Systems: From Molecules to Vehicles. Elsevier Science, Amsterdam.
Schadschneider, A., Klingsch, W., Klüpfel, H., Kretz, T., Rogsch, C., Seyfried, A., 2009. Evacuation dynamics: Empirical results, modeling and applications, in: Meyers, R. (Ed.), Encyclopedia of Complexity and System Science. Springer, p. 3142.
Steffen, B., Seyfried, A., 2010. Methods for measuring pedestrian density, flow, speed and direction with minimal scatter. Physica A 389, 1902.
Zhang, J., Klingsch, W., Schadschneider, A., Seyfried, A., 2011. Transitions in pedestrian fundamental diagrams of straight corridors and T-junctions. J. Stat. Mech. , P06004.
Zhang, J., Klingsch, W., Schadschneider, A., Seyfried, A., 2013. Experimental study of pedestrian flow through a T-junction, in: Traffic and Granular Flow '11. Springer, p. 241.